

**Development of Methodologies for the Estimation  
of Thermal Properties Associated with Aerospace Vehicles**

by

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**ABSTRACT**

Thermal stress analyses are an important aspect in the development of aerospace vehicles such as the National Aero-Space Plane (NASP) and the High-Speed Civil Transport (HSCT) at the National Aeronautics and Space Administration Langley Research Center (NASA-LaRC). These analyses require knowledge of the temperature within the structures which consequently necessitates the need for thermal property data. The initial goal of this research effort was to develop a methodology for the estimation of thermal properties of aerospace structural materials at room temperature and to develop a procedure to optimize the estimation process. This estimation procedure was implemented utilizing a general purpose finite element code. In addition, an optimization procedure was developed and implemented to determine critical experimental parameters to optimize the estimation procedure. Finally, preliminary experiments were conducted at the Aircraft Structures Branch (ASB) laboratory.

**INTRODUCTION**

Researchers within the ASB at NASA-LaRC are currently investigating the thermal stresses associated with aerospace structures. In these studies, the temperature distribution within the material must be known, and it can be determined using a mathematical model of the system which in turn requires knowledge of the thermal properties of the structural materials. Many of these properties are unknown and/or difficult to determine, and important considerations, such as anisotropic behavior, complex geometries, and extreme temperature ranges, must be taken into account.

The strategy used for this investigation was to start with a simple problem and increase its complexity incrementally. Therefore, the initial objective was to develop a methodology for the estimation of the thermal properties of isotropic materials at room temperature and to design optimal experiments to determine these properties. The research plan involved the utilization of a general purpose finite element code currently used by the ASB, called EAL<sup>1</sup>, in the estimation procedure, the design of in-house experimentation at the ASB laboratory, and the provision for flexibility and adaptability to allow for future evaluation of complex materials and structures over extreme temperature ranges. The primary significance of this work is that it enables accurate thermal modelling which can later be used for thermal stress analysis. In addition, the methodology utilized permits the design of optimal experiments for the estimation of thermal properties, and provides LaRC researchers greater flexibility and time efficiency

through the adaptability of the procedure and the development of in-house experiments. Furthermore, the methodologies developed as a result of this research can also be utilized in the development of estimation procedures for the determination of structural properties.

### ESTIMATION PROCEDURE

The estimation procedure is based on the minimization of an objective function which contains experimental and calculated temperature data with respect to the unknown thermal properties. The objective function was simply defined as a least squares function which contains the difference between calculated and measured temperatures. The minimization procedure used was based on the Gauss minimization method, which was modified using the Box-Kanemasu Modification<sup>2</sup>. Inherent in the minimization procedure are sensitivity coefficients which are the derivatives of temperature with respect to changes in the property under consideration. The calculated temperatures were obtained from a mathematical model of the system. In this model, one-dimensional heat transfer was assumed with known temperature and heat flux boundary conditions. The resulting temperature distribution was calculated using EAL.

### EXPERIMENTAL DESIGN AND OPTIMIZATION

A simple geometry using flat plate samples was chosen for the experimental design. A thin resistance heater was used to supply the heat flux boundary condition. To ensure symmetry, the heater was sandwiched between two composite samples of equal thickness. Thermocouples were placed on either side on the heater to measure temperature, and the composite sandwich was placed between two copper blocks with thermocouples on either side of the samples. The copper blocks were used to approximate a constant temperature boundary condition. The entire assembly was held together in a simple press and placed in a uniform temperature oven. A schematic of the experimental setup is shown in Figure 1.

Prior to implementation of the experimental procedure, the experimental parameters, including the total experimental time, the heating time and the sensor location, were determined using an optimization procedure which maximized the sensitivity of temperature to changes in the thermal properties. The optimal parameters were obtained by maximizing the determinant of a matrix containing the product of time averaged sensitivity coefficients.

### RESULTS AND DISCUSSION

The estimation procedure was developed using EAL. Initially, simulated experimental data with and without added random errors were used to test the procedure. The experimental optimization procedure was then implemented, and the results for the determination of the optimal heating time and sensor location are shown in Figures 2 and 3, respectively. Finally, preliminary experiments were conducted using 5260/IM7 composite samples. Future work will include the analysis of the experimental data using the estimation procedure for the estimation of the thermal properties, and the modification of the procedure to estimate anisotropic thermal properties over extreme temperature ranges.

#### REFERENCES

1. Whetstone, W.D., 1983, EISI-EAL Engineering Analysis Language, Engineering Information Systems, Inc., San Jose, CA.
2. Beck, J.V., and Arnold, K.J., 1977, Parameter Estimation in Engineering and Science, John Wiley and Sons, NY.

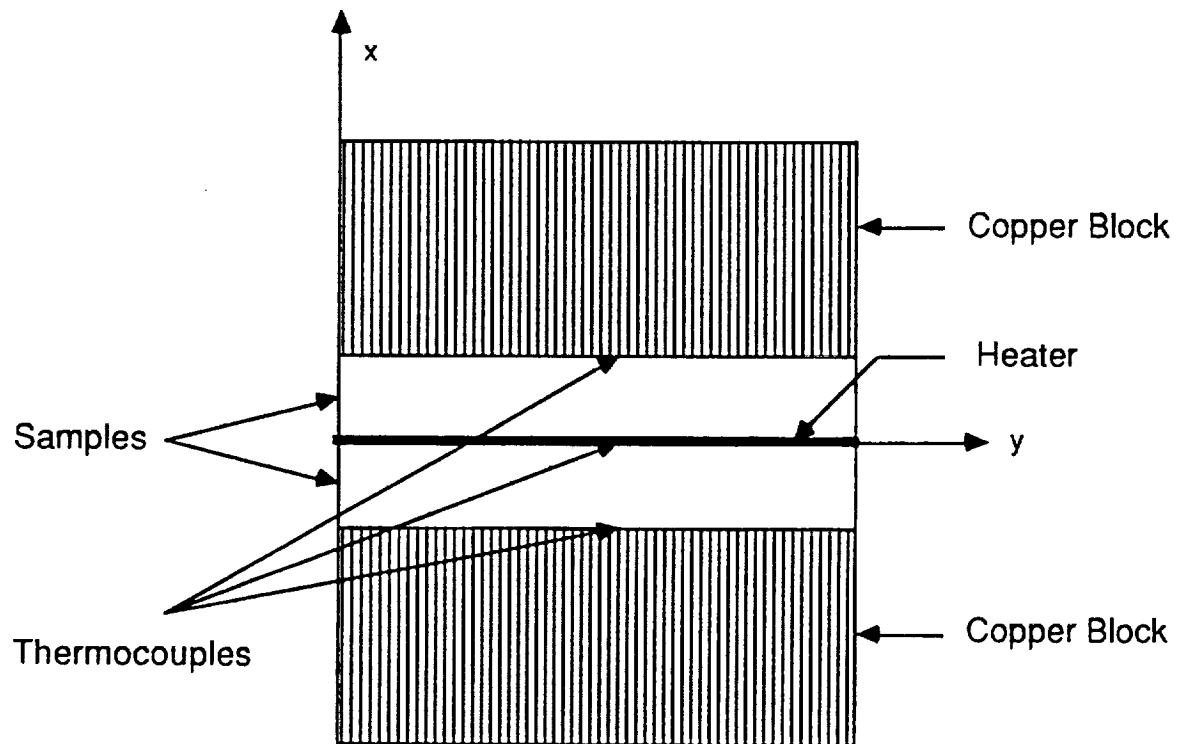


Figure 1. Experimental Set-up.

# Determinant, $D$ , for Various Heating Times ( $x^+ = 0.0$ )

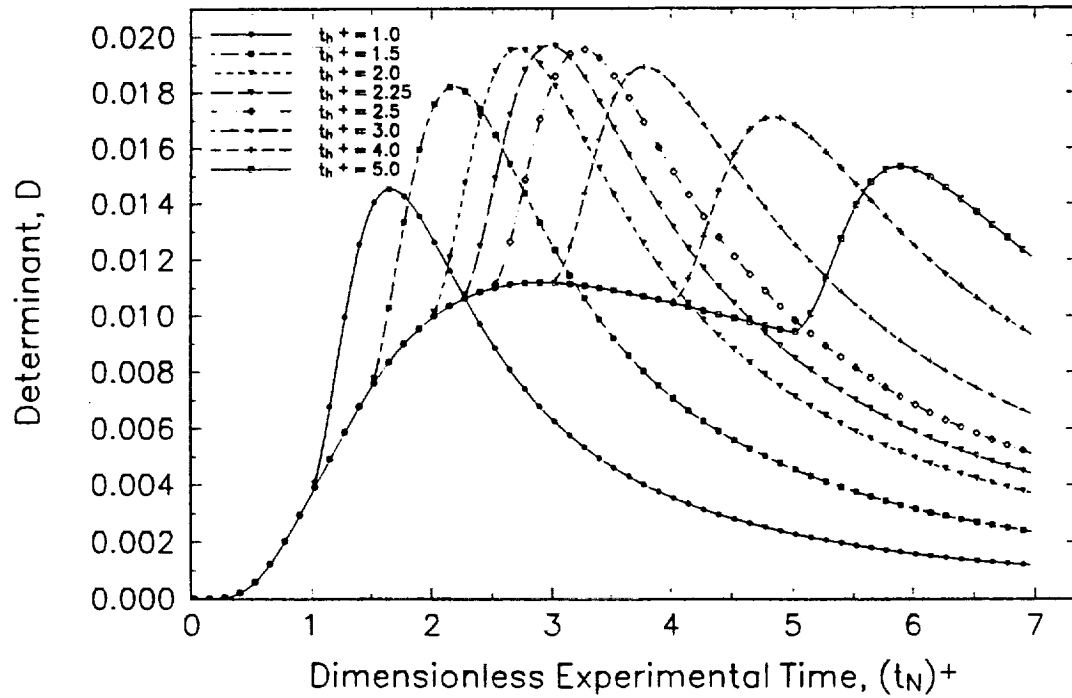


Figure 2. Determination of Optimal Heating Time,  $t_h^+$  ( $\alpha t/L^2$ ;  $\alpha$  = thermal diffusivity,  $t$  = time,  $L$  = sample thickness), from the Maximum Determinant,  $D_{\max}$ .

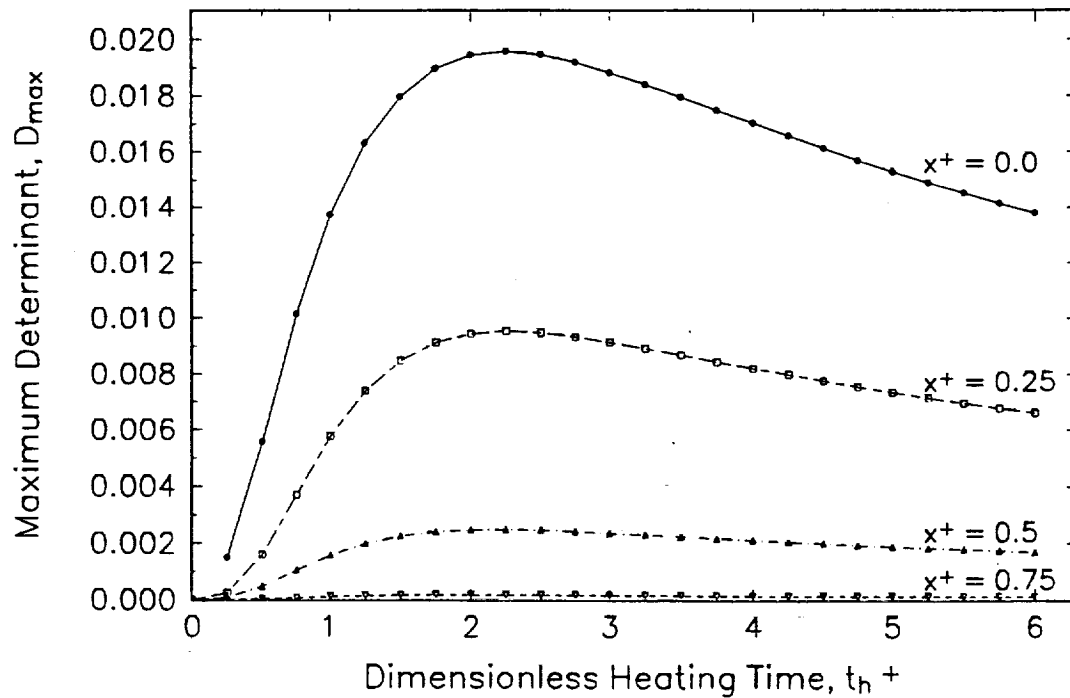


Figure 3. Determination of Optimal Sensor Location,  $x^+$  ( $x/L$ ;  $x$  = sensor location,  $L$  = sample thickness), from the Maximum Determinant,  $D_{\max}$ .